INTEIN MEDIATED PEPTIDE LIGATION

BACKGROUND OF THE INVENTION

Genetic engineering is a powerful approach to the manipulation of proteins. However, genetic methodologies are constrained by the use of only naturally coded amino acids. Furthermore, cytotoxic proteins are difficult to obtain by expression and isolation from a living source, since the expression of the toxic protein can result in death of the host.

To some extent, protocols have been developed to circumvent these problems, for example, total chemical synthesis (Kent, S. B. (1988) *Ann. Rev. Biochem.* 57:957-989), use of misacylated tRNAs (Noren, et al., (1989) *Science* 244:182-188), and semi-synthetic techniques (reviewed in Offord, R. (1987) *Protein Eng.* 1:151-157; Roy. et al. (1994) *Methods in Enzymol.* 231:194-215; Wallace, C. J. (1993) *FASEB* 7:505-515). However, all of these procedures are limited by either the size of the fragment which can be generated or by low reaction yield.

It would therefore be desirable to develop a high-yield, semi-synthetic technique to allow *in vitro* fusion of a synthetic protein or peptide fragment to an expressed protein without limitation as to the size of the fused fragments.

Likewise, in order to produce cytotoxic proteins, it would be desirable to develop a method of fusing a synthetic fragment, *in vitro*, to an inactive, expressed protein, so as to restore protein activity post-production from the host.

The modified Sce VMA intein has been used to generate thioester-tagged proteins for use in ligation (Example 19, U.S.S.N. 08/811,492, filed June 16, 1997; Chong, (1996) *J. Biol. Chem.*, 271(36):22159-22168; Chong, (1997) *Gene*, 192:271-281; and Muir, et al. (1998) *Proc. Natl. Acad. Sci* USA 95:6705-6710).

Some disadvantages have been low yields due to poor cleavage of the Sce VMA intein with thiol-reagents that are optimum for ligation, the need for large peptide quantities due to on-column reactions, the use of odoriferous reagents, and/or low protein yields due to the use of a large, eukaryotic intein.

SUMMARY OF THE INVENTION

In accordance with the present invention, there is provided a method for producing a semi-synthetic fusion protein *in vitro*, comprising the steps of producing a target protein fused to a protein splicing element (an intein) and selectively cleaving the fusion and ligating a synthetic

protein or peptide at the C-terminal thioester of the target protein, which overcome many of the disadvantages and problems noted above. Specifically, the present invention has higher yields due to better thiol-induced cleavage with thiol reagents which have been optimized for the ligation reaction. Off-column ligation allows for sample concentration as well as the use of less peptide. In a particularly preferred embodiment, thiol reagents such as 2-mercaptoethanesulfonic acid (MESNA), which is an odorless thiol-reagent, is used for cleavage and ligation along with the Mxe intein, which is from a bacterial source and often expresses better in bacterial cells. Furthermore, the present invention allows peptides to be directly ligated to the thioester bond formed between an intein and the target protein. The present invention also provides a method for producing a cytotoxic protein, comprising the steps of producing a truncated, inactive form of the protein *in vivo* which is fused to a protein splicing element, and selectively cleaving the fusion and ligating a synthetic protein or peptide at a C-terminal thioester of the target protein to restore the activity of the native cytotoxic protein. Recombinant vectors for producing such cleavable fusion proteins are also provided.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a flow diagram depicting the chemical reactions which enable intein-mediated peptide ligation. The

thioester generated at the C-terminus of the target protein during IMPACT™ purification was used in a 'native chemical ligation' reaction. This allowed the ligation of a synthetic peptide to a bacterially expressed protein. A typical ligation reaction involved the expression of the target protein-intein-CBD fusion followed by binding to a chitin resin. A thiol reagent induced cleavage of the intein. The target was eluted from the chitin resin and a synthetic peptide was added. The ligation reaction proceeded overnight.

Figure 2 is a gel depicting the results of cleavage and ligation reactions using various thiols. Cleavage and ligation reactions with different thiols visualized on 10-20% Tricine gels. MYB (a fusion protein of maltose binding protein-Sce VMA intein (N454A)-chitin binding domain) and MXB (a fusion protein of maltose binding protein-Mxe GyrA (N198A) intein-chitin binding domain) were incubated overnight at 4°C with various thiols (50 mM) in 150 mM Tris, 100 mM NaCl, pH 8 in the presence of a 30 amino acid peptide with an N-terminal cysteine. The peptide ligates to the C-terminus of MBP. Lanes 1-5 ligation with MYB. Lane 1 no thiol. Lane 2 dithiothreitol. Lane 3 2-mercaptoethanesulfonic acid. Lane 4 3-mercaptopropionic acid. Lane 5 thiophenol. Lanes 6-10 ligation with MXB. Lane 6 no thiol. Lane 7 dithiothreitol. Lane 8 2-mercaptoethanesulfonic acid. Lane 9 3-mercaptopropionic acid. Lane 10 thiophenol.

Figure 3 is a gel depicting direct ligation of a peptide to the thioester formed between the Sce VMA intein and maltose binding protein. SDS-PAGE of direct ligation reaction with a 10-20% Tricine gel. Lane 1: a precursor protein (MYBleu) consisting of maltose binding protein-Sce VMA1 intein-chitin binding domain was heated to >95°C for 5 minutes in a buffer of 50 mM Trizma base, pH 8.5 containing 100 mM NaCl, 1% SDS, and mM tris-(2-carboxyethyl)phosphine (TCEP) followed by overnight incubation at room temperature. The precursor (MYBleu) is visible along with the Sce VMA1 intein (Y) and maltose binding protein (M), which are cleavage products. Lane 2: the precursor protein was subjected to the same conditions as described in Lane 1 except that the 30 amino acid peptide (1 mM) was added. The precursor (MYB) and cleavage products (Y and M) are visible along with the ligation product (M+30mer) formed when the 30 amino acid peptide fuses to maltose binding protein.

Figure 4 is a diagram depicting the pTXB1 expression vector of Example I (SEQ ID NO:7 and SEQ ID NO:8).

Figure 5 is the DNA sequence of pTXB1 (SEQ ID NO:5).

Figure 6 is a gel depicting the results of the *Hpa*I protein ligation reaction. Protein ligation reactions examined on 10-20% Tricine gels. Lane 1: clarified cells extract after IPTG (0.5 mM) induction of ER2566 cells containing the pTXB2-*Hpa*I

plasmid. The fusion protein of *Hpal*$_{223}$-Mxe GyrA-intein-CBD (52 kDa) is visible. Lane 2: cell extract as in Lane 1 after passage over a chitin column, which results in the binding of the fusion protein. Lane 3: *Hpal*$_{223}$ (25.7 kDa) after cleavage from the fusion protein by addition of MESNA. Lane 4: ligation product of *Hpal*$_{223}$ (0.2 mg/mL) with 1 mM of a 31 amino acid peptide (ligation product 29.6 kDa), representing the residues necessary to generate full length *Hpa*I, after overnight incubation at 4°C. Lane 5: full length *Hpa*I from a recombinant source (29.6 kDa) containing BSA (66 kDa) and two impurities.

Figure 7 is a western blot of various proteins ligated to a biotinylated peptide. Proteins purified with the Mxe GyrA IMPACT™ derivative were ligated to a synthetic peptide which contained an antibody recognition sequence.

DETAILED DESCRIPTION OF THE INVENTION

The ligation methods of the present invention are based on the discovery that a cysteine or peptide fragment containing an N-terminal cysteine may be fused, *in vitro*, to a bacterially expressed protein produced by thiol-induced cleavage of an intein (U.S. Patent No. 5,496,714; Example 19 of U.S.S.N. 08/811,492 filed June 16, 1997; Chong, et al., (1996) *supra* and Chong, et al., (1997) *supra*.

The ligation procedure disclosed herein utilizes a protein splicing element, an intein (Perler, et al., (1994) *Nucleic Acids Res.* 22:1125-1127) to precisely create a thioester at the C-terminal α-carbon of an expressed protein. This reactive thioester could be present between the target protein and intein or generated by the addition of a thiol reagent. Previously the generation such a thioester was described using an intein (CIVPS) that was modified to undergo thiol inducible cleavage at its N-terminal junction in the presence of thiol reagent dithiothreitol (DTT) (Chong, et al. (1997) *supra*; Comb, et.al. U.S. Patent No. 5,496,714). This C-terminal thioester was previously used in a 'native chemical ligation' type reaction (Dawson, et al., (1994) *Science* 266:776-779) to fuse ^{35}S-cysteine or a peptide fragment containing an N-terminal cysteine to a bacterially expressed protein (Example 19, Comb, et.al. U.S. Patent No. 5,834,247, Chong (1996) *supra* and Chong (1997) *supra*.

The ligation method of the instant invention begins with the purification of the thioester-tagged target protein using an intein as described (Chong, et.al. (1997) *supra*). The direct ligation method of the instant invention begins with the isolation of a precursor composed of the target protein-intein-CBD. In one preferred embodiment, the host cell is bacterial. In other embodiments the host cell may be yeast, insect, or mammalian. A cysteine thiol at the N-terminus of a synthetic peptide nucleophilicly attacks a thioester present

on the freshly isolated C-terminal α-carbon of the target protein or directly attacks the thioester present between the target protein and intein. This initially generates a thioester between the two reactants which spontaneously rearranges into a native peptide bond (Figure 1).

In order to optimize the ligation efficiency so that greater than 90% of the bacterially expressed target protein can be fused to the synthetic peptide or protein, specific thiol reagents and inteins are screened. In a preferred embodiment, the intein may be any CIVPS, such as *Sce* VMA, *Mxe* GyrA or derivatives of mutants thereof, and the thiol reagent is 2-mercapto-ethanesulfonic acid, thiophenol, DTT, or 3-mercaptopropionic acid (Comb, et al., U.S. Patent No. 5,496,714; U.S. Patent No. 5,834,247).

In one particularly preferred embodiment, an intein whose protein splicing activity has been blocked by mutation is utilized. The mutant must, however, retain the ability to undergo the N-S shift, thus allowing thioester formation between itself and an N-terminal protein. This thioester can then be nucleophilicly attacked by a thiol reagent or by the N-terminal cysteine of a peptide sequence. For example, by mutating the C-terminal asparagine (asn 198) of an intein from the GyrA gene of *Mycobacterium xenopi* (Telenti, et al., (1997) *J Bacteriol* 179:6378-6382) to an alanine created a

thiol inducible cleavage element. This modified intein cleaved well with thiol reagents that were optimal for the ligation reaction, such as MESNA and thiophenol. Furthermore, optimal thiol reagent and intein combinations can be determined by incubating a precursor protein containing the intein of interest with a wide variety of thiol reagents followed by determination of the extent of cleavage of the precursor protein (Figure 2).

The use of such intein and specific thiol reagents leads to optimal yields and high ligation efficiencies; typically greater than 90% of the N-terminal ligation fragment can be modified.

The ligation methods of the present invention expand the ability to incorporate non-coded amino acids into large protein sequences by generating a synthetic peptide fragment with fluorescent probes, spin labels, affinity tags, radiolabels, or antigenic determinants and ligating this to an *in vivo* expresed protein isolated using a modified intein.

Furthermore, this procedure allows the isolation of cytotoxic proteins by purifying an inactive truncated precursor from a host source, for example bacteria, and generating an active protein or enzyme after the ligation of a synthetic peptide. For example, restriction endonucleases which have not successfully been cloned by traditional

methods may be produced in accordance with the present invention.

Also, the direct ligation procedure allows the ligation of a protein or peptide sequence to another protein or peptide sequence without the use of exogenous thiol reagents. Direct ligation relies on the nucleophilic attack of the N-terminal amino acid of one peptide on the thioester formed between a target protein and an intein (Figure 3).

In summary, a fusion protein can be created using the methods of the present invention that possesses unique properties which, currently, can not be generated genetically.

The Examples presented below are only intended as specific preferred embodiments of the present invention and are not intended to limit the scope of the invention. The present invention encompasses modifications and variations of the methods taught herein which would be obvious to one of ordinary skill in the art.

The references cited above and below are herein incorporated by reference.

EXAMPLE I

Creation of vectors pTXB1 and pTXB2 for ligation:

Asparagine 198 of the *Mxe* GyrA intein (Telenti, et al., (1997) *J Bacteriol.* 179:6378-6382) was mutated to alanine by linker insertion into the *Xmn*I and *Pst*I sites of pmxeMIPTyrXmnSPdel to create pMXP1. The *Xmn*I site was originally introduced into the unmodified *Mxe* GyrA intein sequence by silent mutagenesis. The *Pst*I site was a unique site in the plasmid. The linker was composed of mxe#3 (5'-GGTTCGTCAGCCACGCTACTGGCCTCACCGGTTGATAGCTGCA-3') (SEQ ID NO:1) and mxe#4 (5'-GCTATCAACCGGTGAGGCCAGTAG CGTGGCTGACGAACC-3') (SEQ ID NO:2).

Into pMXP1 another linker composed of mxe#1 (5'-TC GAATCTAGACATATGGCCATGGGTGGCGGCCGCCTCGAGGGCTCTTCC TGCATCACGGGAGATGCA-3') (SEQ ID NO:3) and mxe#2 (5'-CTAG TGCATCTCCCGTGATGCAGGAAGAGCCCTCGAGGCGHGCCGCCACCCA TGGCCATATGTCTAGAT-3') (SEQ ID NO:4) was inserted into the *Xho*I and *Spe*I sites to introduce a multiple cloning site (*Xba*I-*Nde*I-*Nco*I-*Not*I-*Xho*I-*Sap*I) before the *Mxe* GyrA intein (pMXP2).

The 0.6 kilobase *Not*I to *Age*I fragment of pMXP2 was ligated into the same sites in pTYB1 (IMPACT kit. New England Biolabs, Beverly, MA) and the *Nco*I to *Age*I fragment of pMXP2

was cloned into pTYB3 (IMPACT kit, New England Biolabs, Beverly, MA) to create plasmids pTXB1 (see Figure 4 and 5) (SEQ ID NO:5) and pTXB2, respectively. These vectors have a multiple cloning site upstream of the modified *Mxe* GyrA intein-chitin binding domain fusion. This allows the insertion of a target gene of interest inframe with the intein and chitin binding domain (CBD).

Creation of vectors pMYBleu for ligation:

pMYBleu was as described in Chong, et al., (1998), *J. Biol. Chem.* 273:10567-10577. This vector consisted of maltose binding protein upstream of the Sce VMA intein-chitin binding domain. A leucine is present at the -1 position instead of the native residue (which is a glycine).

Purification of Thioester-Tagged Proteins:

Protein purification was as described using the *Sce* VMA intein (Chong, et.al., (1997) *Gene* 192:271-281) with slight modification. ER2566 cells (IMPACT T7 instruction manual from New England Biolabs, Beverly, MA) containing the pTXB vector with the appropriate insert were grown to an OD_{600} of 0.5-0.6 at 37°C at which point they were induced with 0.5 mM IPTG overnight at 15°C. Cells were harvested by centrifugation and lysed by sonication (performed on ice). The

three part fusion protein was bound to chitin beads (10 mL bed volume, Figure 6, lanes 1 and 2) equilibrated in Buffer A (50 mM Tris, pH 7.4, and 500 mM NaCl), and washed with 10 column volumes of Buffer A to remove unbound material.

Cleavage was initiated using a buffer of 50 mM 2-mercaptoethanesulfonic acid (MESNA), 50 mM Tris, pH 8.0 and 100 mM NaCl. Other thiol reagents were also used at other times, such as thiophenol, dithiothreitol, and/or 3-mercaptopropionic acid. After overnight incubation at from 4-25°C protein was eluted from the column (Figure 6 lane 3). This protein contained a thioester at the C-terminus.

Purification of MYB. MYBleu and MXB:

Full length precursor proteins consisting of maltose binding protein-*Sce* VMA intein (N454A)-chitin binding domain (MYB) and maltose binding protein-*Mxe* GyrA (N198A) intein-chitin binding domain (MXB) were purified after induction and sonication, as described above, by applying the sonicated sample to a 10 mL column of amylose resin (New England Biolabs, Beverly, MA). Unbound proteins were washed from the column with 10 column volumes of Buffer A (see purification of thioester-tagged proteins) Bound proteins were eluted with a buffer of 50 mM Tris, pH 8, containing 100 mM NaCl and 10 mM maltose. Fractions were collected and protein

concentrations were determined using the Bio-Rad Protein Assay (Hercules, CA).

Peptide Synthesis:

Peptides for subsequent ligation reactions were synthesized on an ABI model 433A peptide synthesizer utilizing *FastMoc*™ chemistry (Fields, et al., (1991) *Pept Res* 4, 95-101) at a 0.085 mmol scale. Preloaded HMP (p-hydroxymethylphenoxymethyl) polystyrene resins (Applied Biosystems, Foster City, CA) functionalized at 0.5 mmol/g was used in conjunction with Fmoc/NMP chemistry utilizing HBTU amino acid activation (Dourtoglou, et al., (1984) *Synthesis* 572-574; Knorr, et al., (1989) *Tetrahedron Lett* 30, 1927-1930). Fmoc amino acids were purchased from Applied Biosystems (Foster City, CA).

Synthesis proceeded with a single coupling during each cycle. Peptide cleavage from the resin and simultaneous removal of side chain protecting groups was facilitated by the addition of cleavage mixture (Perkin Elmer, Norwalk, CT) consisting of 0.75 g phenol, 0.25 mL 1,2-ethanedithiol, 0.5 mL deionized H_2O, and 10 mL TFA. The resin was flushed with nitrogen and gently stirred at room temperature for 3 hours. Following filtration and precipitation into cold (0°C) methyl-t-butyl ether, the precipitate in the ether fraction was

collected by centrifugation. The peptide precipitate was vacuum dried and analyzed by mass spectrometry using a Perceptive Biosystems (Framingham, MA) MALDI-TOF mass spectrometer.

Final purification was by HPLC using a Waters HPLC system with a Lambda-Max Model 481 Multiwavelength detector (set at 214 nm), 500 series pumps and automated gradient controller with a Vydac semi-preparative C18 column. Elution of the peptide was with a 60 minute linear gradient of 6-60% acetonitrile (v/v) in an aqueous solution of 0.1% TFA (v/v).

Protein Cleavage and Ligation Reactions:

Cleavage of MYB and MXB: The precursor protein (1 mg/mL) was incubated overnight at 4°C with or without a thiol reagent (50 mM) in 150 mM Tris, pH 8, containing 100 mM NaCl.

Ligation reactions with MYB and MXB: The precursor protein (1 mg/mL) was treated as described for cleavage except that a 30 amino acid peptide (1 mM final concentration, NH_2-CAYKTTQANKHIIVACEGNPYVPVHFDASV-COOH (SEQ ID NO:6) was also included in the reaction (Figure 2).

Ligation reactions after purification of thioester-tagged proteins: Lyophilized peptides (New England Biolabs, Beverly, MA) were added (to 1 mM final concentration) directly to the thioester-tagged protein freshly isolated from the chitin column. The reaction was allowed to proceed overnight at from 4-25°C. In both ligation procedures the condensation of the reactants is visible on a 10-20% Tricine gel (Figure 6). The ligation reaction was tested in conditions of 5-150 mM Tris or HEPES buffers, 50-1000 mM NaCl, 10 mM Maltose, and pH 6-11 and 0-6 M Urea.

Direct Ligation Reactions:

MYBleu (1 mg/mL) was incubated in 6 M Urea or 1% SDS, pH 7.5-8.5, 50-200 mM NaCl, and 1 mM of a 30 amino acid peptide (NH_2CAYKTTQANKHIVVACEGNPYVPVHFDASV-COOH (SEQ ID NO:6)). The MYBleu was incubated for 0-180 minutes at either 4°C or 100°C prior to the addition of the 30 amino acid peptide. Ligation reactions proceeded overnight at either 4°C or 25°C.

EXAMPLE II

Labeling a target protein: Maltose Binding Protein

Maltose binding protein (MBP, 42 kDa) was isolated as described in Example I above using the IMPACT procedure (IMPACT manual from New England Biolabs, Inc., Beverly, MA) in the presence of MESNA.

A biotinylated peptide possessing an N-terminal cysteine (CDPEK*DS-COOH (SEQ ID NO:9)), in which the biotin was attached to the ε-amino group of the lysine residue) was ligated to the freshly purified target protein as described above. Briefly, 4 μL of biotinylated peptide (10 mM) were mixed with a 36 μL aliquot of the freshly purified MBP sample. The mixture was incubated at 4°C overnight.

Western blots with alkaline phosphatase linked anti-biotin antibody detected the presence of the ligated product but not the unligated target protein (Figure 7). The efficiency of the ligation is typically greater than 90% when MESNA is used for cleavage.

EXAMPLE III

Labeling a target protein: Bst DNA Polymerase I Large Fragment (Bst Pol 1)

Bst DNA Polymerase I large fragment (67 kDa) was isolated as described in Example I above using the IMPACT procedure (IMPACT manual from New England Biolabs, Inc., Beverly, MA) in the presence of MESNA.

A biotinylated peptide possessing an N-terminal cysteine (CDPEK*DS-COOH (SEQ ID NO:9)), in which the biotin was attached to the ε-amino group of the lysine residue) was ligated to the freshly purified target protein as described. Briefly, 4 μL of biotinylated peptide (10 mM) were mixed with a 36 μL aliquot of the freshly purified Bst Pol 1 sample. The mixture was incubated at 4°C overnight.

Western blots with alkaline phosphatase linked anti-biotin antibody detected the presence of the ligated product but not the unligated target protein (Figure 7). The efficiency of the ligation is typically greater than 90% when MESNA is used for cleavage

EXAMPLE IV

Labeling a target protein: Paramyosin

Paramyosin (29 kDa) was isolated as described in Example I above using the IMPACT procedure (IMPACT manual from New England Biolabs, Inc., Beverly, MA) in the presence of MESNA.

A biotinylated peptide possessing an N-terminal cysteine (CDPEK*DS-COOH (SEQ ID NO:9)), in which the biotin was attached to the ε-amino group of the lysine residue) was ligated to the freshly purified target protein as described. Briefly, 4 μL of biotinylated peptide (10 mM) were mixed with a 36 μL aliquot of the freshly purified paramyosin sample. The mixture was incubated at 4°C overnight.

Western blots with alkaline phosphatase linked anti-biotin antibody detected the presence of the ligated product but not the unligated target protein (Figure 7). The efficiency of the ligation is typically greater than 90% when MESNA is used for cleavage.

EXAMPLE V

Labeling a target protein: *E. coli* Thioredoxin

E. coli thioredoxin (12 kDa) was isolated as described in Example I above using the IMPACT procedure (IMPACT manual from New England Biolabs, Inc., Beverly, MA) in the presence of MESNA.

A biotinylated peptide possessing an N-terminal cysteine (CDPEK*DS-COOH (SEQ ID NO:9)), in which the biotin was attached to the ε-amino group of the lysine residue) was ligated to the freshly purified target protein as described. Briefly, 4 μL of biotinylated peptide (10 mM) were mixed with a 36 μL aliquot of the freshly purified thioredoxin sample. The mixture was incubated at 4°C overnight.

Western blots with alkaline phosphatase linked anti-biotin antibody detected the presence of the ligated product but not the unligated target protein (Figure 7). The efficiency of the ligation is typically greater than 90% when MESNA is used for cleavage.

EXAMPLE VI

Isolation of a cytotoxic protein:

The ligation procedure of Example I was applied to the isolation of a potentially cytotoxic protein. An endonuclease from *Haemophilus parainfluenzae* (*Hpa*I; Ito, et al., (1992) *Nucleic Acids Res* 20:705-709) was generated by ligating an inactive truncated form of the enzyme expressed in *E. coli* (ER2566 cells, New England Biolabs, Inc., Beverly, MA) with the missing amino acids that were synthesized chemically.

The first 223 amino acids of *Hpa*I (full length *Hpa*I is 254 amino acids) were fused in frame with the modified *Mxe* GyrA intein and the CBD. The 223 amino acid *Hpa*I fragment was isolated as described for purification of thioester tagged proteins. The truncated *Hpa*I displayed no detectable enzymatic activity.

A synthetic peptide representing the 31 amino acids needed to complete *Hpa*I was ligated onto the 223 amino acid truncated form of *Hpa*I by the method of Example I.

Enzymatic Assay for *Hpa*I:

The activity of the fused *Hpa*I was determined by its ability to digest Lambda DNA (New England Biolabs, Beverly, MA). Serial dilutions of ligated or truncated *Hpa*I, with the appropriate peptide added to 1 mM, were incubated with 1 μg of Lambda DNA for 1 hour at 37°C in a buffer of 20 mM Tris-acetate, pH 7.9, 10 mM magnesium acetate, 50 mM potassium acetate, 1 mM dithiothreitol, and 170 μg/mL BSA (total volume 30 μL). Digestion reactions were visualized on 1% agarose gels permeated with ethidium bromide. One unit of *Hpa* I was defined as the amount of enzyme necessary to digest 1 μg of Lambda DNA in one hour at 37°C.

The newly ligated *Hpa*I had a specific activity of 0.5-1.5x10^6 units/mg which correlated well with the expected value of 1-2x10^6 units/mg for the full length enzyme.